

POLYTECHNIC INSTITUTE OF BROOKLYN-GRADUATE CENTER
ROUTE 110-FARMINGDALE, NEW YORK 11735-MYRTLE 4-5500

DEPARTMENT OF ELECTROPHYSICS

15 May 1970

Quarterly Status Report No. PIBEP-69-039.4

For the Period:

1 January 1970 - 31 March 1970

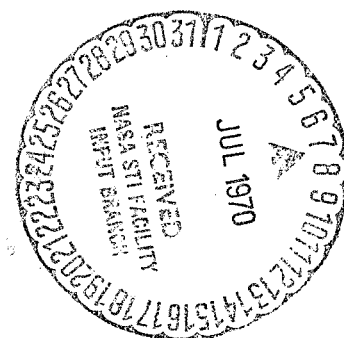
Grant No. NGR 33-006-047
Supplement No. 1

Grant Title:

"An Investigation of Diffraction by Planetary Atmospheres"

Prepared for:

National Aeronautics and Space Administration
Washington, D.C. 20546



FACILITY FORM 602

N70-73950

(ACCESSION NUMBER)

(THRU)

8

(PAGES)

None

(CODE)

CR-110429

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

Submitted by,

Stanley H. Gross

Stanley H. Gross
Principal Investigator

ABSTRACT

A method was investigated for determining tangential gradients in a medium from the residual doppler when the points of nearest approach of a set of rays do not lie along a vertical line. First order approximation to phase and bending along a ray was assumed to be valid and the bending was assumed to be due primarily to the radial gradient. Using these approximations it was found that simultaneously obtained residual doppler for two frequencies yields a set of expressions that can be solved to separate the doppler due to the radial gradient and that due to the horizontal gradient. Abel inversion of these separated components yield the horizontal and radial gradients along the locus of points of nearest approach.

Preliminary results obtained from a model ionosphere in which the approximations are valid are reported.

Plans for continued efforts are also covered.

ACKNOWLEDGEMENT

This work was supported by the National
Aeronautics and Space Administration under Grant
No. NGR 33-006-047.

I. INTRODUCTION

This report is a quarterly report of effort under NASA Grant NGR 33-006-047, Supplement 1, for the period 1 October 1969 to December 31 1969. The program is under the direction of Dr. Stanley H. Gross of the Electrophysics Department of the Polytechnic Institute of Brooklyn. Reported herein are the results of efforts during the period covered and plans for continuing the study for subsequent periods.

The intent of the study is to investigate the problem of diffraction by a planetary atmosphere or ionosphere utilizing ray theoretical and full wave methods for models of increasing complexity in which the ultimate contains ionization realistically varying, not only radially, but with latitudinal and longitudinal coordinates. Results obtained with the more complex models will be compared with the simpler, purely radial model, such as has been used to interpret Mariner occultation data, to establish errors resulting from the assumption of a radially symmetric spherical distribution. It is also an intent of the study to determine the degree of definition attainable by multi-frequency measurements and to provide information that may suggest other and newer types of experiments to measure the atmosphere or ionosphere of the planets. The results of the analysis may also provide a more logical basis for comparison of measurement techniques for use on future planetary missions.

Neither ray theoretical nor full-wave analysis techniques have previously been applied to models incorporating angular variation as well as radial variation. In line with starting with the simplest, an exponential model had been defined during previous reporting periods with electron density or neutral density falling off with altitude and with factors introducing angular dependence to present a meaningful variation with latitude and longitude. Ray equations for this model were studied assuming angular symmetry about some direction, such as the sun's. It was established that analytic solutions could not be given in closed form and that approximation methods and numerical analysis were necessary. Major parameters that account for non-planarity, skewness and asymmetry were determined. Computations were made for incoming parallel rays, each differing by its impact parameter to determine various ray properties such as output directions, minimum distance, impact parameters, non-planarity, ray bending, curvature, torsion, phase length

and the important parameter $q = \mu r \sin \psi$ which varies along a ray, unlike rays in a radially symmetric model (Snell's law). An important property was discovered. It was found for physically meaningful values of the parameters that variations were small with respect to corresponding rays for a radially symmetric model defined utilizing the parameters at the minimum point of a ray. Since these parameters vary from ray to ray for an angularly varying model, no single radially symmetric model is suitable for the complete family of rays, except under special geometric conditions. Deviations from this finding become significant only for larger values of the parameter controlling the degree of refraction.

Analytic approximation techniques were then used based on expansion about the ray's nearest point. Utilizing a straight line emanating from the nearest point as the analytic perturbation method, it was shown that occultation measurements of phase path length, as presently interpreted, yield information as to the medium properties at the minimum point of each ray. For a realistic ionosphere or atmosphere, with angular variation, the line of minimum points is not a vertical line, in general, but rather some slant line. Planetary orbiters and high inclination fly-bys will suffer from this difficulty if measurements are interpreted as yielding the vertical profile.

The exponential model had been extended to include a parabolic region representing an ionospheric peak region with angular variation incorporated to cause the peak to vary with latitude and longitude. Rays had been computed for this model, and it was found necessary to incorporate parametric bounds to delineate conditions under which ray trapping may occur. Further detailed study was shown to be warranted in view of the more complicated caustic surface for this model. The nearest point expansion technique was applied to this model, with similar findings regarding the ray minimum point as for the exponential model. Somewhat greater restrictive conditions are necessary, and angular variation limits interpretation of data for the region about the peak.

Ray focusing utilizing a differential beam area or focusing factor was also introduced into the ray computer equations. The method utilized differentiated ray equations in which differentiation is with respect to parameters describing the initial wave surface, the resultant equations delineating the ray tubes. The computer program was extended to include anisotropic media to

cover the case of an ionosphere imbedded in a magnetic field. Approximation techniques yielded far more complex results with more stringent conditions.

Studies were made of the errors due to the assumption of spherical symmetry by comparing inversion profiles with true profiles of media depending on angular as well as radial coordinates. Significant errors were found for configurations typical of planetary orbiters. Greatest errors are expected for a planet such as Mercury (assuming it has an atmosphere).

Discussions were held at the Institute for Space Studies of the Goddard Space Flight Center with regard to the non-planarity of the Mariner 4 through 7 occultation measurements. Preliminary examination indicated the likelihood that near vertical profiles were determined, though more precise position data are essential to be certain.

A request had been made to A. Kliore of JPL for more precise Mariner 4 through 7 position data to examine occultation results in light of the theory developed from this study. These data have not yet been received.

Effort During Period Reported

The effort in this period has been applied to the derivation of a method for separating the contributions to the residual doppler data due to the radial and horizontal gradients of a planetary ionosphere by the use of multiple frequencies on a single fly-by or orbit of the planet.

The model selected for this study involved an index of refraction of the form $1 + \epsilon N$ where ϵ is a small quantity. The phase length and bending of a ray in this model of a medium are adequately described by expressions to the first order in ϵ . It is also assumed that the radial gradient is much larger than the horizontal gradient, which allows the bending of the ray to be expressed as a function of the radial gradient alone. As had been described in previous reports, these approximations allow any ray to be described in terms of a spherically symmetric medium based on the parameters of the medium at the point of nearest approach of the ray to the planet. Because of this symmetric approximation to a ray path, the gradients that have the primary effect on the doppler are those which are normal to the ray paths at the nearest points of the ray paths.

For the family of rays associated with a particular set of residual doppler data one can, for any ray, express the doppler as the sum of the doppler due to the radial motion and that due to the horizontal motion of successive rays. The bending of any ray is proportional to the doppler of radial motion. Thus one obtains an expression of the doppler, which is known as a function of orbital points, in terms of the components of the doppler as functions of the nearest points, and a second expression, containing the doppler of radial motion, relating the nearest point with its associated orbit point. For a single set of doppler data these expressions cannot be solved. A second set of doppler data obtained simultaneously with the first at a different frequency yields two additional expressions. The four expressions associated with the simultaneously generated sets of doppler information can be combined to obtain a nonlinear differential equation of the radial component of doppler with the radius to the nearest point as the independent variable. This equation, with an appropriate starting procedure, can be solved numerically. The horizontal and vertical gradients along the locus of points of nearest approach are then obtained via an Abel transform utilizing the kinematics of the orbit and the radial and horizontal contributions to the doppler.

Preliminary calculations have been made for the model with a parabolic peak and exponential topside described in previous reports. Two sets of residual doppler data were obtained for an orbit that yielded loci of nearest points along an elliptical path which deviated appreciably from a vertical line. From the residual doppler thus obtained and the orbit information, the components of the doppler due to the radial and horizontal gradients were determined by the method described. The radial component was within 2 percent and the horizontal component within 8 percent of the actual values. The errors appear to increase near the peak but a correction is now being incorporated. Calculation of the gradients by inversion for comparison with actual gradients were not yet made during this period.

Plan for the Forthcoming Period

Investigation of the method described will be continued to improve the results around and below the peak density region. The possibility of extending the method to make it applicable to less tenuous media and to cases in which there may be large horizontal gradients will also be studied.

Some work will be done in establishing descriptions of models with limited parameters to examine best fit methods. Some further error studies will be made to establish the effect of angular variation of density peaks about the planet on the derived distribution about the peak. In all cases from the simplest model to the more complex, the horizontal and radial gradients will be computed for comparison with the actual values to evaluate the method of analysis. It is hoped that Mariner spacecraft trajectory data will become available to check the results of Mariners 4 through 7.

REFERENCES

- Gross, S.H., "An Investigation of Diffraction by Planetary Atmosphere," Quarterly Status Report No. PIBEP-69-039.2, October 1969, Polytechnic Institute of Brooklyn, Long Island Graduate Center, Farmingdale, New York.
- Pirraglia, J. and S.H. Gross, "Latitudinal and Longitudinal Variation of a Planetary Atmosphere and the Occultation Experiment," paper submitted for publication.